Fall Field Trip
Association of Environmental & Engineering Geologists - Carolinas Section
Western Branch of the North Carolina Section of the American Society of Civil Engineers
September 6, 2014

Faults and Landslides - Geologic Structures, Processes and Landforms Important to Engineering and Hydrogeology Projects in the Blue Ridge of Western North Carolina

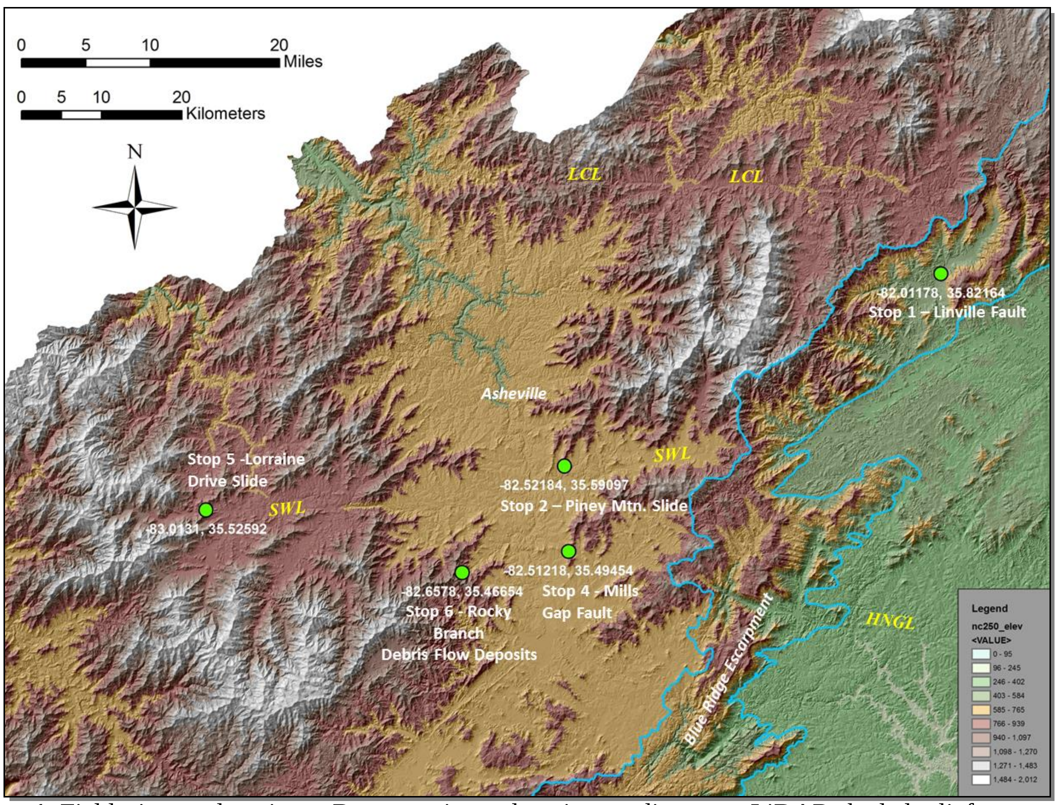

Figure 1. Field trip stop locations. Base map is an elevation gradient on a LiDAR shaded relief map. SWL = Swannanoa lineament; LCL = Laurel Creek lineament; HNGL = Hickory Nut Gorge lineament.

Field Trip Leaders

Nick Bozdog, Bart Cattanach, Rick Wooten - North Carolina Geological Survey

Stephen Fuemmeler – Appalachian Landslide Consultants, PLLC

ALC
Appalachian Landslide Consultants, PLLC

Geological Survey N.C. 1823

Field Trip Stops and Itinerary

Stop	Location	Latitude	Longitude	Miles	Drive Time Minutes	Arrive	Depart	Minutes at Stop	Comments
0	Environment and Natural Resources, 2090 U.S. Highway 70, Swannanoa	35.596	-82.4237				8:00 AM		Field trip begins.
				37	48				
1	Linville Fault U.S. 221	35.822	-82.0118			9:00 AM	10:00 AM	60	Linville fault exposed in a large road cut on US 221, ~14.5mi north of Marion.
				42	48				
2	Piney Mountain Slide, 29 Stonebridge Drive, Asheville	35.591	-82.5218			10:50 AM	11:35 AM	45	Large-scale landslide stabilization of the Piney Mountain landslide in Asheville (topic of presentation at Friday night AEG-ASCE meeting).
				5.1	9				
3	BRP Visitor's Center, Mile Post 384, Blue Ridge Parkway	35.565	-82.4871			11:45 AM	12:45 PM	60	Lunch and pit stop at the Blue Ridge Parkway Visitor's Center.
				7.2	14				
4	Mills Gap Road, City of Asheville water tank	35.495	-82.512			1:00 PM	1:45 PM	45	Brittle faulting and fractures associated with the Mills Gap fault zone.
				35.6	39				
5	Lorraine Drive Slide - Maggie Valley	35.526	-83.0137			2:30 PM	3:15 PM	45	Active landslide affecting US 19-276 and property on Lorraine Drive in Maggie Valley.
				35.7	49				
6	Rocky Branch Debris Flows, Bent Creek Gap Road (U.S.F.S. 479), Bent Creek Experimental Forest (Optional stop depending on time and weather)	35.467	-82.6578			4:15 PM	4:45 PM	30	1977 debris flow deposits, and older debris fan deposits and landforms.
				23.9	38				
7	Asheville Regional Office, Dept. of Environment and Natural Resources, 2090 U.S. Highway 70, Swannanoa	35.596	-82.4237			5:30 PM			Field trip ends.
	Total			187	245				

Stop 1: Linville Falls fault in North Cove

Leaders: Bart Cattanach, Rick Wooten, Nick Bozdog, North Carolina Geological Survey

Location: Road exposure along Hwy 221, North Cove, NC. (Longitude -82.011874W, Latitude 35.821902N)

Purpose: Examine a new exposure of the Linville Falls fault and associated lithologies along the edge of the Grandfather Mountain Window, one of the classic structures in Appalachian geology.

Stop 1 is located on the northwest side of the Grandfather Mountain window, a tectonic window framed by the Linville Falls and Brevard faults. The Grandfather Mountain window is a composite feature with 1,000+ Ma granitic gneisses (Wilson Creek, Blowing Rock, Brown Mountain) at its core (Bryant and Reed, 1970). Failed rifting (~735 Ma) deposited sedimentary and volcaniclastic rocks of the Grandfather Mountain formation unconformably on top of these basement gneisses (Hatcher, 2010). Later, successful rifting during the Neoproterozoic and Cambrian deposited thick rift and drift clastic and carbonate sequences on the eastern margin of proto-North America. Paleozoic orogenic events culminating with the Alleghanian continental collision of proto-Africa and proto North America (~320-290 Ma) created giant mountain chains, deforming, metamorphosing, and thrusting rocks within the collision zone. During this collision, multiple thrust sheets were stacked from east to west on top of proto-North America (Hatcher et al., 2007). The basement gneisses and Grandfather Mountain formation comprise one of the lower thrust sheets that were transported over North American crust and early Paleozoic sedimentary rocks. Continued thrusting placed part of the Cambrian rift sequence containing the

Chilhowee quartzite and Shady dolomite on top of the basement gneisses along the Tablerock fault (Figure 1-2). These rocks were in turn overthrust by 1,000+ Ma basement Cranberry gneiss along the Linville Falls fault (Bryant and Reed, 1970) and high-grade metamorphic paragneisses of the Tallulah Falls/Ashe Metamorphic Suite along the Holland Mountain fault. Additional fault duplexing below these rocks helped to "dome up" the area and erosion has exposed the window into the thrust sheets we see today (Hatcher et al., 2007).

This substantial outcrop (stretching approximately 0.25 miles along U.S. 221 and reaching a height of 325 feet) is an excellent exposure of the Linville Falls fault (LFf). At this location the LFf thrusts the 1200 Ma Cranberry Gneiss (a component of the continental basement) over the 520 Ma Shady Dolomite. This is one of the few easily accessible locations along the Grandfather Mountain Window-basement contact where the Shady Dolomite has not been omitted by faulting. At its type locality the Shady Dolomite is a fine- to coarse-grained, thin- to thick-bedded dark- to light-gray, blue-gray, and white dolomitic limestone but at this outcrop the original dolomite has been recrystallized into a dolomitic marble by strain along the LFf. Near the LFf fault the Shady Dolomite is mylonitic, pyrite bearing and locally sericitic.

The dolomitic marble is exposed at the base of the outcrop and grades successively upward into calcareous phyllonite, ferruginous phyllonite, mylonitic granitic gneiss and semi-massive migmatitic folded orthogneiss. Rocks near the LFf are highly strained and completely overprinted with a mylonitic foliation. Slickenlines and localized breccia zones indicate late stage brittle faulting near the marble-calcareous phyllonite contact. Rocks near the top of the outcrop are slightly less mylonitic and preserve older metamorphic fabrics. Mylonitic foliation generally strikes southwest and dips northwest. Dips range from 18 to 40 degrees and average about 30 degrees throughout the exposure. Immediately to the east, on the opposite bank of the North Fork Catawba River are quartzite exposures of the upper member of the Chilhowee Group that underlies the Shady Dolomite.

The Shady dolomite in North Cove contains karst features such as Linville Caverns and hosts several high-yield wells, making it a valuable resource (Table 1-1). North Cove is also the site of large debris deposits originating on the high-relief slopes surrounding the valley (Figure 1-3). These thick deposits and overburden can make well drilling with traditional air rigs difficult with many drillers declining work in the area. Sedimentation and drill hole caving were difficulties encountered when drilling the private water well located in debris deposits shown in Figure 1-3.

CONTACT NAME	FACILITY ADDRESS	DATE DRILLED	TOTAL DEPTH	CASING DEPTH	WATER LEVEL	YIELD
			feet		feet below land surface	GPM
North Cove Springs	13195 U.S. 221 North	03/16/1994	280	78	50	100
Hogan, John	1595 Old Linville Road	10/16/2002	185	30	30	100
North Cove Springs	13195 U.S. 221 North	06/23/1994	305	75	65	150
Goode, Carol	361 Old Linville Road	03/31/2008	205	177	40	150
North Cove Springs	13195 U.S. 221 North	06/28/1994	305	55	70	190
Coats American	630 American Thread Road	10/29/1993	230	62	60	400
North Cove Elementary School	401 American Thread Road	12/31/2001	250	140	68	500
Baxter Healthcare Corporation	65 Pitts Station Rd	12/15/2002	606	226	14	800
Baxter Healthcare Corporation	65 Pitts Station Rd	12/15/2002	748	228	12	1600

Table 1-1. List of several high-yield wells located within the Shady Dolomite in North Cove, McDowell County, NC. Data provided by NCDENR-Division of Water Resources.

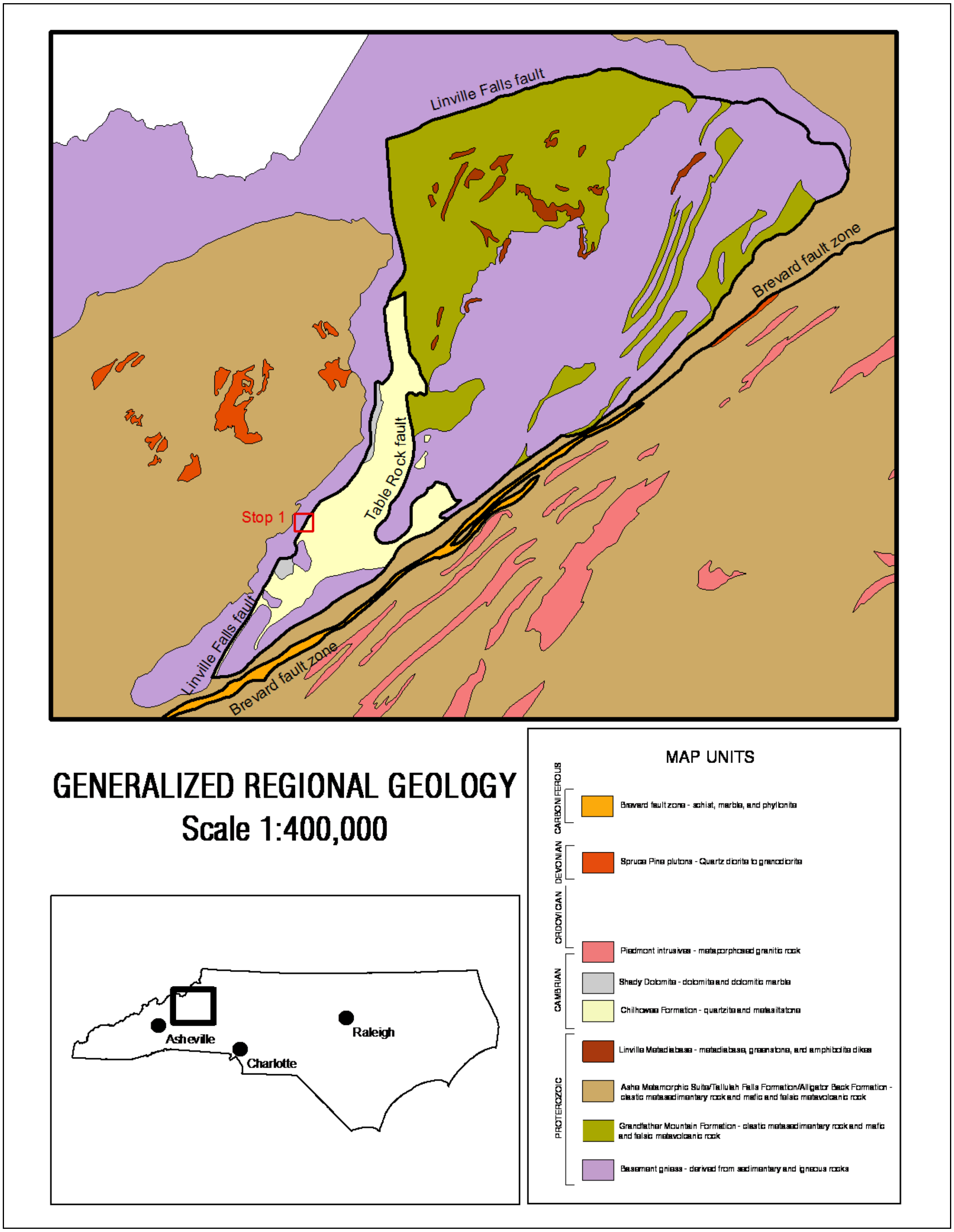

Figure 1-1. Location and general geology of Stop 1 (Modified from 1985 State Geologic Map of North Carolina).

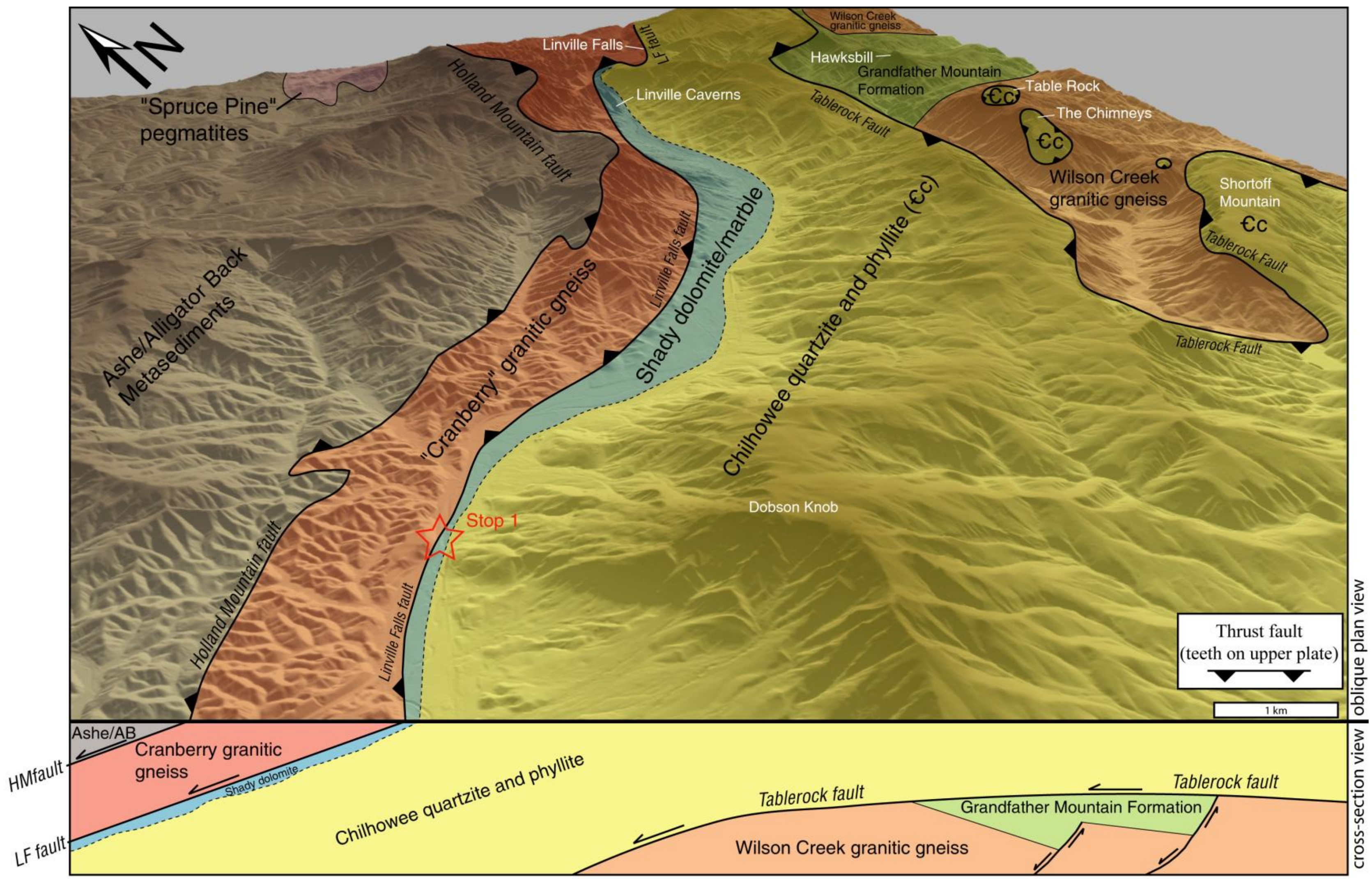

Figure 1-2: Geologic map and cross-section of the North Cove area, McDowell County, NC. 3D LiDar oblique topography provided by Rick Lockamy (NCDOT). Geology modified from Bryant and Reed, 1970.

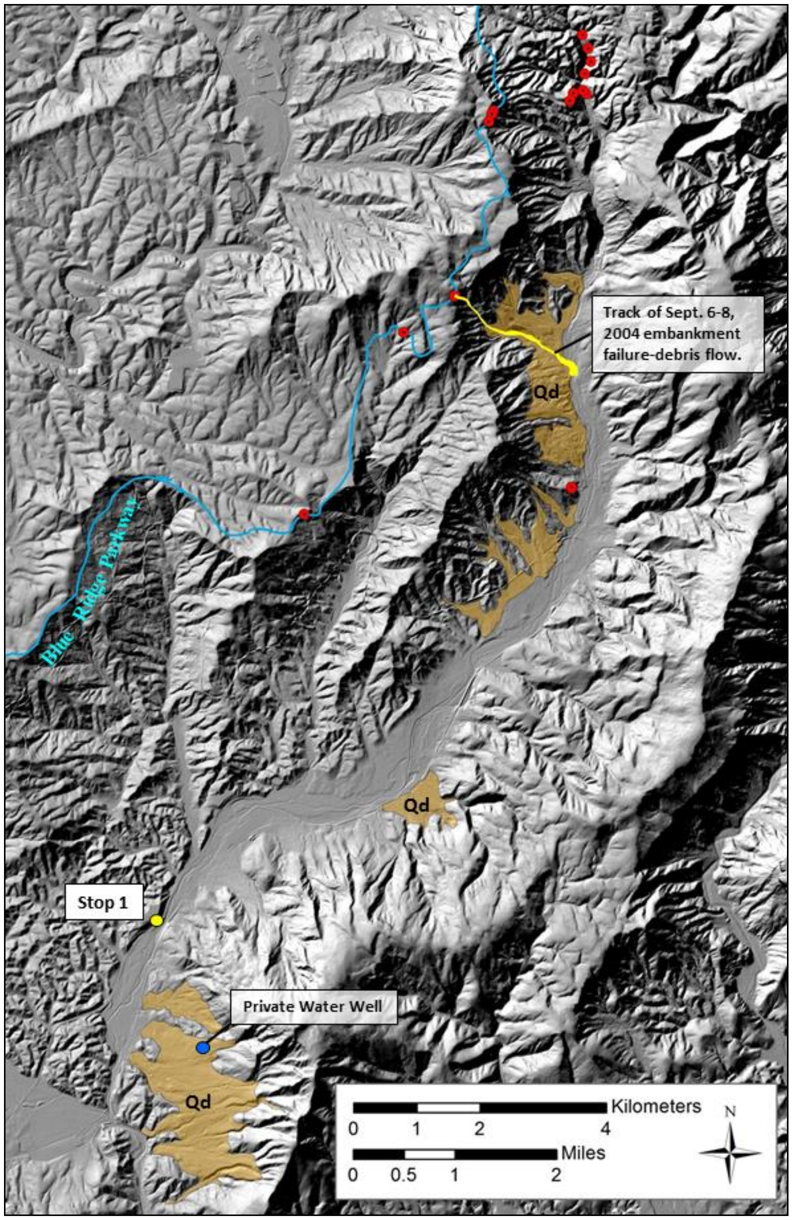

Figure 1-3. LiDAR shaded relief map of the North Cove area showing the location of stop 1 at the Linville fault, and the path of an embankment failure-debris flow on the Blue Ridge Parkway triggered by rainfall from Hurricane Frances, September 6-8, 2004. Qd = Quaternary debris deposits, selected locations adapted from Bryant and Reed, 1970. Red dots = point locations for landslide initiation sites in the NCGS landslide geodatabase.

Reference

Bryant, B., and Reed, J.C., Jr., 1970, Geology of the Grandfather Mountain window and vicinity, North Carolina and Tennessee: U.S. Geological Survey Professional Paper 615, 190 p. map scale1:62,500.

Hatcher, R.D., 2010, The Appalachian orogen: A brief summary, in Tollo, R.P., Bartholomew, M.J., Hibbard, J.P., and Karabinos, P.M., eds., From Rodinia to Pangea: The Lithotectonic Record of the Appalachian Region: Geological Society of America Memoir 206, p. 1-19.

Hatcher, R.D, Lemiszki, P.J., and Whisner, J.B., 2007, Character of rigid boundaries and internal deformation of the southern Appalachian foreland fold-thrust belt, *in* Sears, J.W., Harms, T.A., and Evenchick, C.A., eds., Whence the Mountains? Inquiries into the Evolution of Orogenic Systems: A Volume in Honor of Raymond A. Price: Geological Society of America Special Paper 433, p. 243-276.

Stop 2. Piney Mountain Landslide

Leader. Stephen Fuemmeler, Appalachian Landslide Consultants, PLLC.

Location. The Piney Mountain site is located on the east side of Asheville, within city limits (Figure 2-1). The landslide is situated above a densely developed neighborhood, Stonebridge, consisting of 62 houses. Longitude -82.521841W, Latitude 35.59097N.

Background. The year of 2013 was exceptionally wet in Western North Carolina, producing precipitation amounts almost 30 inches above normal. In addition to triggering hundreds of landslides in WNC, it exacerbated problems for some landslides that had been moving very slowly for years prior to these rains. This stop, the Piney Mountain landslide in Asheville, is an example of this latter scenario. It was a very slowly moving weathered rock slide whose movement rate increased dramatically in 2013, threatening the Stonebridge subdivision below. This project highlights the need for geologists and engineers to work together on stabilization projects in areas with complex geology, such as Western North Carolina. Through a collaborative effort and a bank willing to go above and beyond what was necessary to protect the subdivision below, the Piney Mountain landslide was stabilized one year after the project began.

Landslide Details. Stonebridge was developed between 1998 and 2003. The Piney Mountain landslide has been active since at least 2006, a small retaining was built behind the house immediately below the landslide and the landslide remained quiet for a number of years. In late 2012, a bank foreclosed on a parcel above Stonebridge valued at $1.1 million. Unbeknownst to the bank, they also became the owners of the Piney Mountain landslide and enormous liability.

Above average rainfall begins to soak WNC beginning in January, 2013. The homeowner below the landslide contacted a local bank representative in May, 2013, and sent them pictures of soil spilling over the retaining wall behind their house (Figure 2-2).

AEI Consultants first came to the site on May 16, 2013, and quickly began an emergency excavation of the encroaching soil to prevent damage to the house. Dense vegetation masked the full extent of the landslide until a portion of the site was cleared for geotechnical work and Appalachian Landslide Consultants, PLLC (ALC) visited the site in July, 2013.

The geotechnical exploration performed jointly by Gentry Geotechnical Engineering, PLLC and ALC and the geological analysis done by ALC revealed a narrow, 600 foot long section of completely weathered bedrock sliding along a compositional layering in the bedrock approximately 10 feet below the ground surface (Figures 2-2 & 2-3). The failure plane was angled at 16 degrees, roughly parallel to the ground slope. Lab tests of the soil indicated an effective friction angle of 39 degrees. The lab results suggest a vastly different soil strength than what was actually taking place onsite as shown by ALC's analysis. A repair that was not informed by the underlying geology could have had disastrous results. Fortunately, the collaborative nature of this project ensured that this critical information was understood by the design engineers at Hayward Baker Inc.

The final design was in place by September, 2013 and construction began as soon as it was approved by the city in November. The design consisted of 3 tiered retaining walls. A lower block wall to replace the original small retaining wall behind the house, a large soldier pile wall a short distance upslope, and a soil nail wall midway up the slope. The tiered wall system was necessary due to the long and shallow sliding surface. Major stabilization work was completed in April, 2014 and the project was complete in September, 2014.

Conclusion. In the end, the bank foreclosing on this property was best the thing that happened to Stonebridge subdivision below. The foreclosed property was initially valued at $1.1 million and was collateral against an $800,000 loan. The bank spent approximately $5 million to stabilize the landslide and protect the neighborhood below. If this landslide was not stabilized, it is likely that several houses would have been impacted by the landslide and Stonebridge would have been left with on-going debris clean-up, long-term endangerment to the neighborhood, and reduced property values.

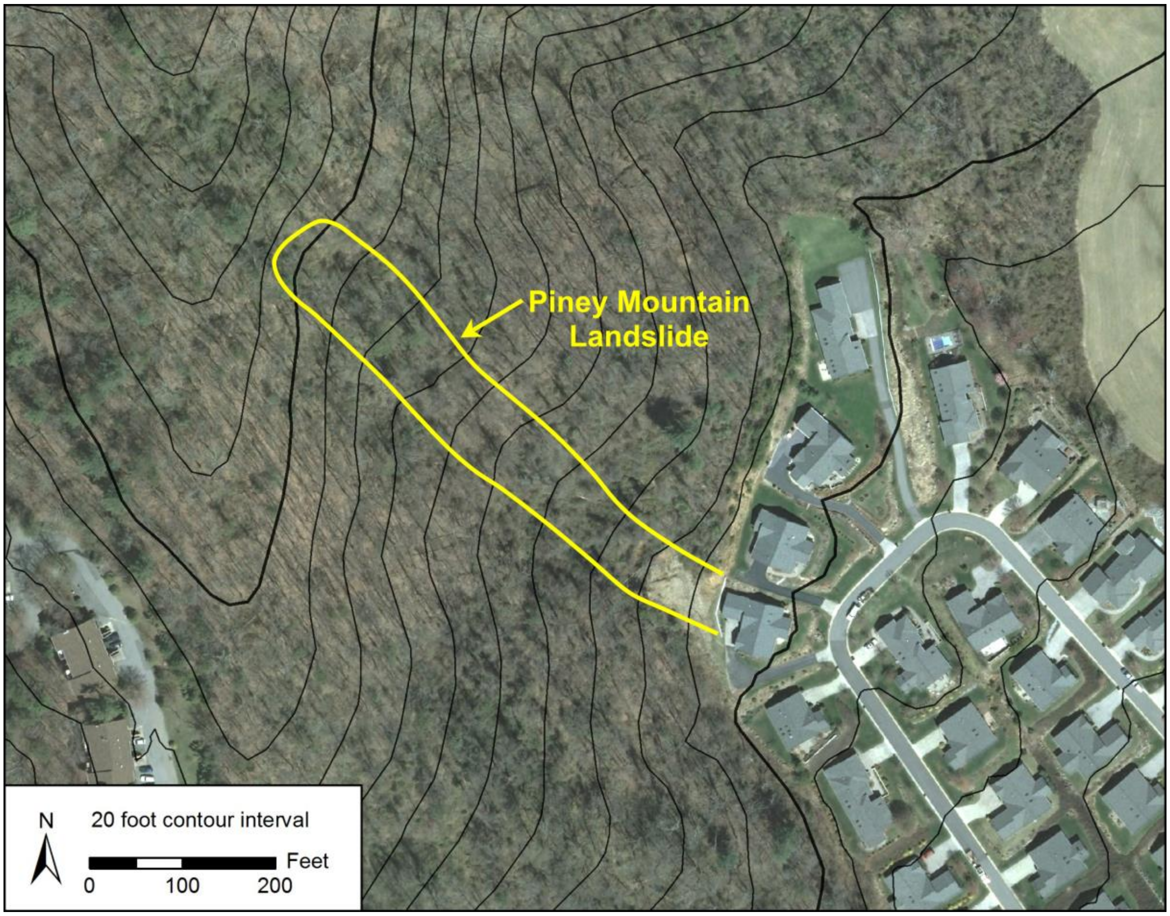

Figure 2-1. Extent of the Piney Mountain landslide. Map base is 2010 orthophotography.

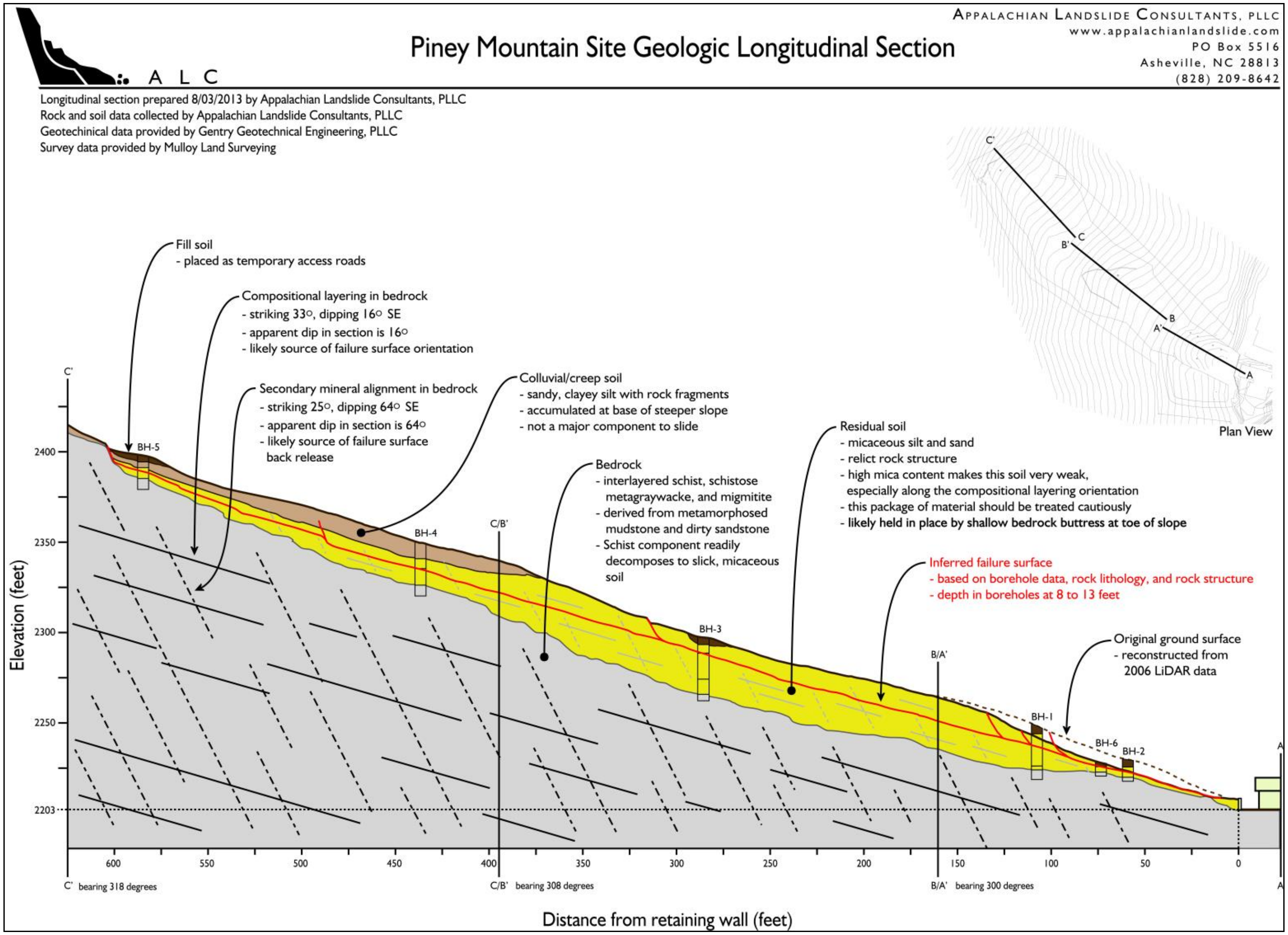

Figure 2-2. Longitudinal section of the Piney Mountain landslide.

Figure 2-3. Oblique view of the slope stabilization at the Piney Mountain landslide.

Stop 3. Lunch at the Blue Ridge Parkway Visitors Center, Mile Post 384 Blue Ridge Parkway.

Stop 4. Mills Gap fault zone.

Leaders. Rick Wooten, Bart Cattanach, Nick Bozdog, North Carolina Geological Survey

Location: Mills Gap Road, Asheville, North Carolina; bedrock exposure on the south side of the water supply tank owned and operated by the City of Asheville Water Resources Department. Longitude -82.512025W, Latitude 35.49488N.

Purpose: Examine fractures and faulting associated with the Mills Gap fault zone, a WNW-ESE trending brittle fault zone with normal and oblique-normal displacement in metasedimentary rocks of the Ashe Metamorphic Suite.

Background. The geologic investigation of the Mills Gap Road area by the N.C. Geological Survey (Wooten and others, 2010) was undertaken to augment the borehole geophysical studies by the U.S. Geological Survey (Chapman and Huffman, 2010) in the area. The purpose of these parallel studies was to assist the U.S. Environmental Protection Agency (EPA) Region 4 Superfund Section in developing a geologic framework and conceptual groundwater flow model for contaminant investigations in the vicinity of the CTS Corporation of Asheville site (CTS site). These joint efforts contributed to the listing of the CTS site on the National Priorities List in March of 2012.

The EPA (U.S. EPA, 2014a, b) provides the following basic information on the CTS site. The CTS of Asheville was operated from 1952 until 1985 as an electronic components manufacturing and electroplating facility. In 1991 CTS notified the State of North Carolina of contamination at the site. The contaminants associated with the site are volatile organic compounds, primarily trichloroethene (TCE). Subsurface soil contamination below the building footprint is serving as a continued source of ground water contamination in the area. The highest TCE concentration in soil (830,000 parts per billion) was found at a depth of 32-34 feet beneath the building. TCE contamination in ground water has not been fully characterized, and is migrating from the site in an uncontrolled plume within fractured bedrock. The EPA has identified one spring-fed water source and six wells that serve as private water supplies that are contaminated with TCE (Figs. 4-2, 3). In June of 2014 the EPA relocated three families living near the CTS site because of elevated levels of TCE in the air inside their homes.

General Geology. Rocks in the Mills Gap area are metamorphosed sedimentary and igneous rocks of the Late Proterozoic to Early Paleozoic Ashe Metamorphic Suite-Tallulah Falls Formation (Figures 4-1, 2, 3, 4). Lithologies consist of metagraywacke, schistose metagraywacke, garnet-mica schist, and amphibolite. A high-temperature ductile fabric defined by compositional layering, preferred grain shapes and mica orientations is the dominant foliation within the rocks. This foliation is strongly folded and was produced during regional sillimanite-grade metamorphism and partial migmatization. A later foliation defined by axial planar mica growth and phyllonite/mylonite zones is also identified. The phyllonite and mylonite zones occur primarily in the NNE-SSE trending Pinner Cove shear zone (Fig. 4-3) and within the WNW-ESE trending Mills Gap fault zone (MGFZ). Sulfide-bearing and tourmaline-bearing quartz veins exhibit ductile and brittle fabric and are thought to be late-stage hydrothermal solutions related to Paleozoic metamorphism. Brittle faulting and fracturing overprint ductile fabrics in the MGFZ.

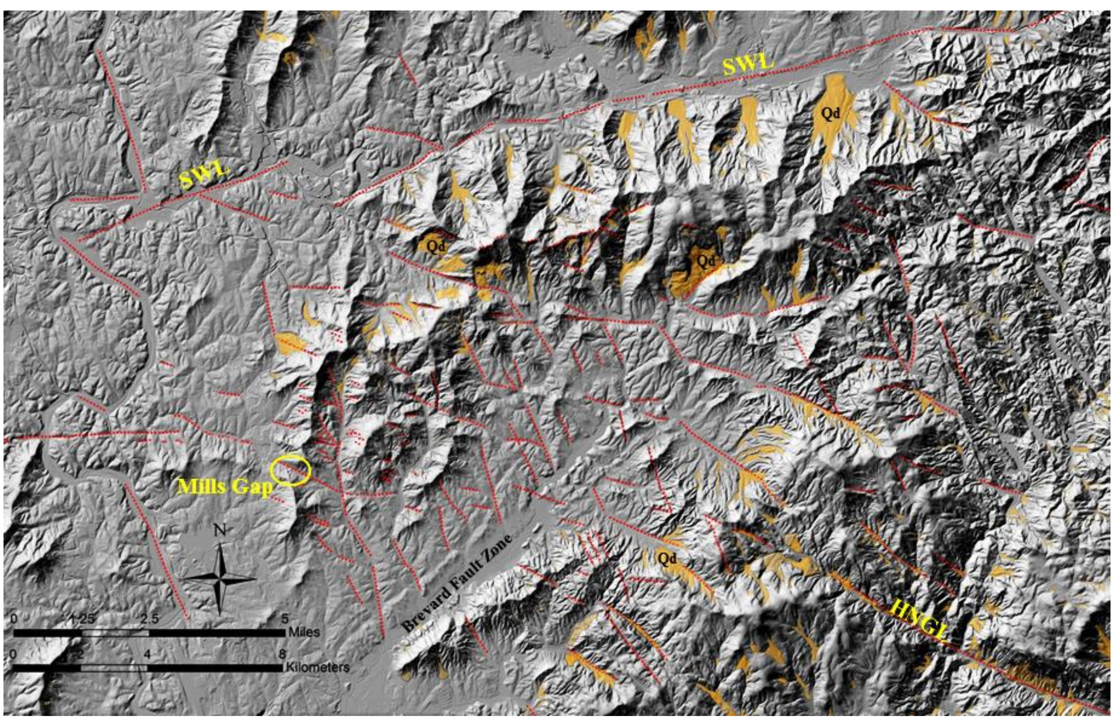

Figure 4-1 Shaded relief map derived from a 6m-pixel resolution LiDAR DEM showing Mills Gap and selected topographic lineaments (red dashed lines) oblique to the overall NE-SW trend of bedrock units and the Brevard fault zone. SWL = segments of the Swannanoa lineament, HNGL = westward extent of the main segment of the Hickory Nut Gorge lineament, Qd = Quaternary debris deposits.

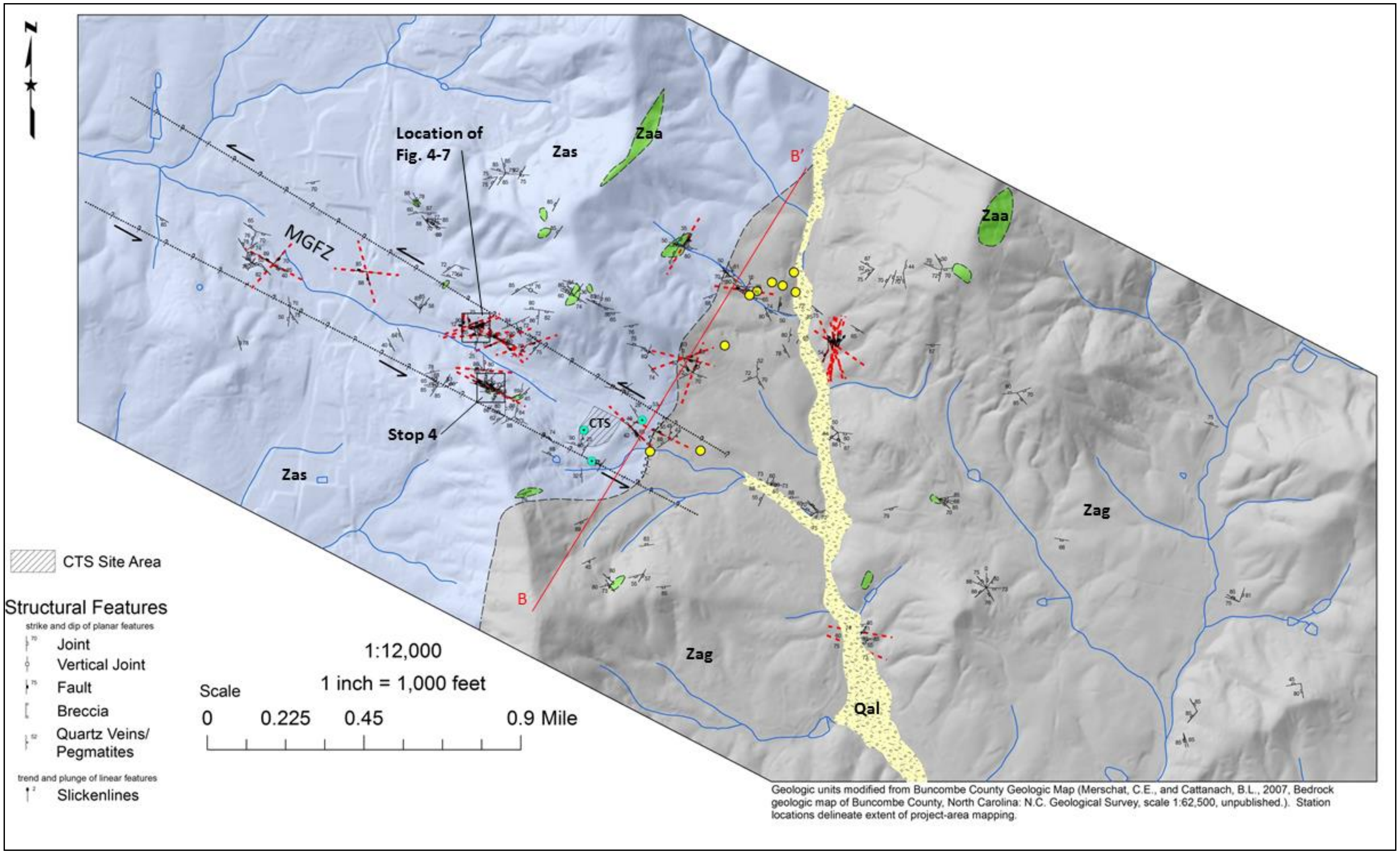

Figure 4-2 Generalized geologic map of the Mills Gap area showing brittle structural features and the known extent of the Mills Gap fault zone (MGFZ). Red dashed lines = strike of brittle faults extended beyond outcrop; Qal = Quaternary alluvium; Zaa = amphibolite; Zag = metagraywacke with lesser granule metaconglomerate, schistose metagraywacke, schist and amphibolite; Zas = schistose metagraywacke and schist with lesser metagraywacke and amphibolite. Yellow-black dashed lines = trends of quartz, and tourmaline-quartz veins. Red strike and dip bars = mylonitic foliation. Blue dots = water wells not contaminated with TCE. Yellow dots = water wells contaminated with TCE.

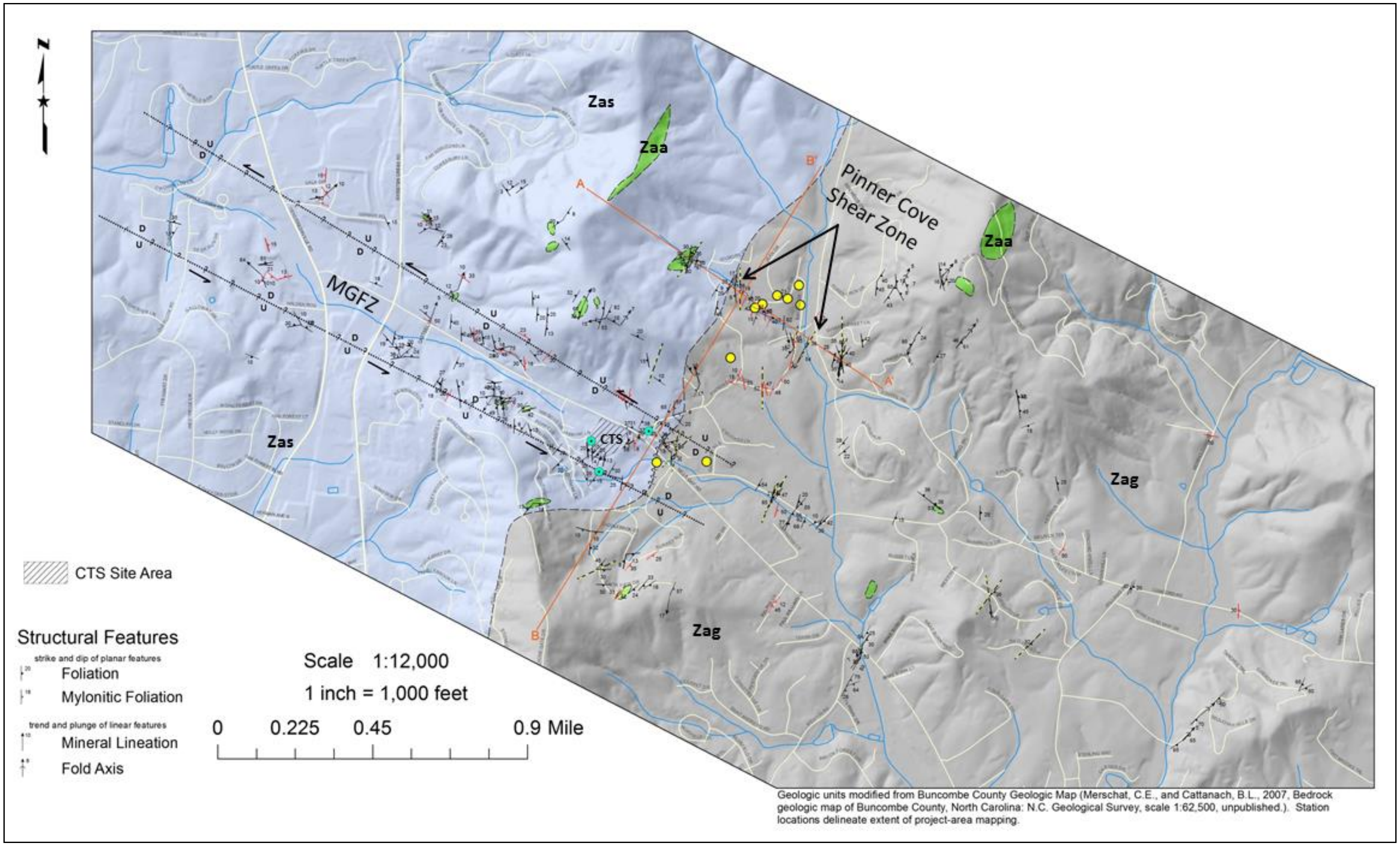

Figure 4-3 Generalized geologic map of the Mills Gap area showing ductile structural features and the known extent of the Mills Gap fault zone (MGFZ). Zaa = amphibolite; Zag = metagraywacke with lesser granule metaconglomerate, schistose metagraywacke, schist and amphibolite; Zas = schistose metagraywacke and schist with lesser metagraywacke and amphibolite. Yellow-black dashed lines = trends of quartz, and tourmaline-quartz veins. Red strike and dip bars = mylonitic foliation. Outcrop width of the NNE-SSW trending Pinner Cove shear zone indicated by arrows. Blue dots = water wells not contaminated with TCE. Yellow dots = water wells contaminated with TCE.

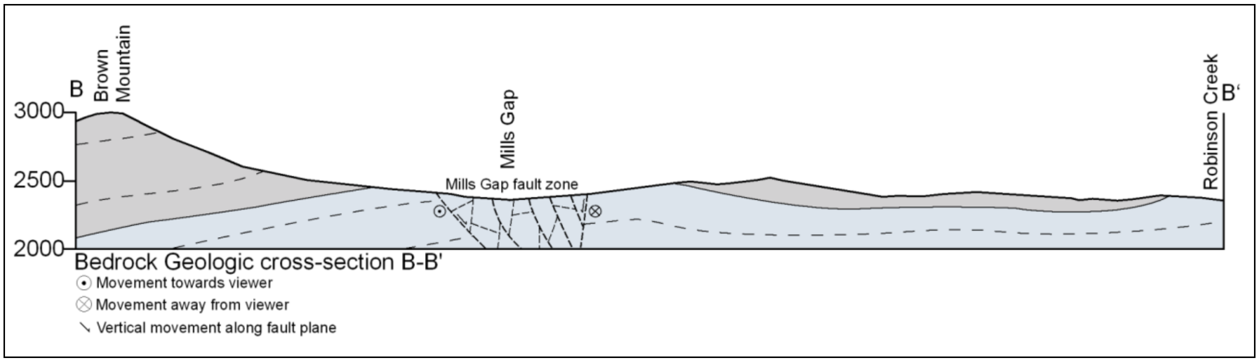

Figure 4-4 Cross section B-B' normal to the Mills Gap fault zone

Mills Gap Fault Zone. The WNW-trending Mills Gap fault zone (MGFZ) occupies a linear topographic low of the same general trend (azimuth 115-295°) as the outcrop-scale brittle structures in the Mills Gap area, and it is aligned the regional Hickory Nut Gorge lineament and numerous localized topographic lineaments and (Figs. 1, 4-1. A brittle fault zone approximately 100m wide and at least 2km long has been identified by the presence of gouge, breccias and the realignment of older ductile fabrics. In many outcrops it appears as a deeply weathered, oxidized, saprolite with clast-supported and clast-in-matrix fabrics. Locally the fault is in contact with and deforms unconsolidated colluvial (?) deposits. In numerous locations proximal to the MGFZ bedrock foliation and compositional layering, and a later mylonitic foliation, are incrementally realigned from a regional NE-SW trend into a WNW-ESE trend subparallel to the MGFZ.

Observed fracture and fault data are consistent with a transtensional-flower structure model. The following field evidence supports the interpretation that the MGFZ is a brittle, transtensional fault system that formed a graben-like structure of intersecting faults, rather than a single, through-going fault plane.

1. Kinematic indicators (e.g., slickenlines, drag folding) indicate strike-slip and oblique-normal components of movement (Fig. 4-7).
2. Fault planes on the MGFZ margins typically dip toward the core of the fault zone, i.e., fault planes on the NE margin of the MGFZ dip toward the SW, whereas on the SW margin, fault planes dip to the NE.
3. Along the margins of the MGFZ the strike of bedrock foliation is typically subparallel to the fault, and dips away from the core of the fault zone, i.e., along the NE margin of the MGFZ bedrock foliations typically dip to the NE, while along the SW margin of the MGFZ, bedrock foliations typically dip to the SW.

Stereonet analyses of over 186 brittle fractures (Fig. 4-8) define a prominent steeply dipping set parallel with the brittle fault zone as well as a conjugate set having an azimuth of 75-255°. Fractures that have similar orientations to the MGFZ [azimuth 115-295º (±15º)], and the conjugate set [azimuth 85-265º (±15º)] occur outside the mapped extent of the MGFZ in a corridor about1.3km wide and at least 2.4km long within the study area.

The WNW-ESE and conjugate ENE-WSW trends of brittle features associated with the MGFZ are similar in orientation to brittle features recognized further to the east in the North Carolina Piedmont. Wooten and others (2001) identified similarly oriented cross-basin faults in Triassic sedimentary rocks of the Deep River Basin. Heller and others (1997, 1998) and Stoddard and Heller (1998) identified brittle faults characterized by siliceous breccia and with similar WNW-ESE and ENE-WSW orientations offsetting crystalline rocks of the North Carolina Piedmont. Garihan and others (1993) considered the brittle faulting in the Marietta-Tryon graben in the nearby Inner Piedmont of South and North Carolina to be mid-Mesozoic with coeval faulting and diabase dike intrusion. Bartholomew and others (2007, 2009) concluded that joints with similar WNW-ESE orientations in ~300 Ma granites exposed in Georgia and South Carolina are likely of Triassic age. They also identified joints and faults of similar trends in South Carolina Coastal Plain deposits of Eocene age.

In more recent work Hill (2013), and Hill and Stewart (2012) interpreted the Swannanoa and Laurel Creek lineaments to have formed in an extensional stress field related to post-orogenic doming of the Blue Ridge in the Miocene. This doming resulted in differentially uplifted blocks bounded by conjugate fracture zones. Our work suggests that the ENE-WSW faults in the MGFZ are possibly related to similarly oriented faults and fractures in the Swannanoa and Laurel Creek lineaments, and that these fault and fractures are components of a coeval conjugate system. The similar orientations and styles of faulting in the MGFZ to those in the Piedmont and nearby Blue Ridge suggest that the brittle, transtensional faulting in the MGFZ is Mesozoic or younger in age. Given that at least one fault in the MGFZ deforms unconsolidated colluvial (?) deposits (Fig. 4-7) at least one period of movement in the conjugate system may have been during the Tertiary or possibly Pleistocene.

Figure 4-5. Stop 4 Location. A Normal or oblique-normal brittle fault (black dashed line) associated with the Mills Gap fault zone (MGFZ) in migmatitic metagraywacke and schistose metagraywacke at the west end of the outcrop at Stop 3. Red arrows show the sense of movement. Fault offset is probably on the scale of 5 feet or less. The dip angle of the fault zone varies, in general, being steeper at the top of the exposure, and flattening towards the bottom right of the photograph. Strike and dip of the fault plane = 294/60 at the labeled location. The lighter colors along the trace of the fault show an area of enhanced weathering in the fractured and brecciated rock. **B:** Close-up view of enhanced fracturing and weathering along the fault; and, drag-folding of a metagraywacke layer in the footwall of the fault.

Figure 4-6. Stop 4 Location. Outcrop showing enhanced weathering along fractures parallel to the WNW-ESE trending Mills Gap Fault Zone (MGFZ). Ice indicates seepage zones along low dip angle foliation and fracture planes, and moderate dip angle fracture planes subparallel the MGFZ. These fracture sets can also influence the stability of rock slopes.

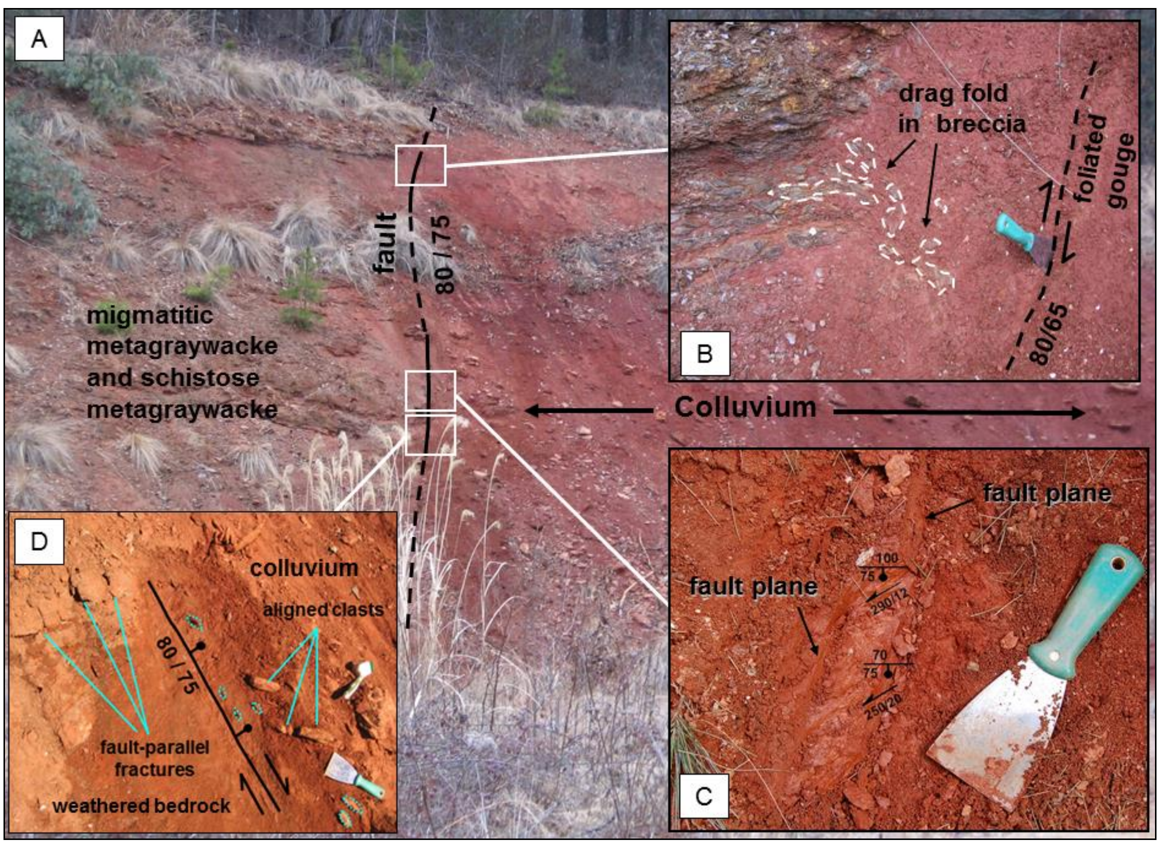

Figure 4-7. A. Fault within the Mills Gap fault zone (MGFZ) exposed in a cut slope. The main fault separating bedrock and colluvium here is generally oriented 80/75, and is a conjugate fault within the main WNW-ESE trend of the MGFZ. **Inset B:** Drag folding in brecciated schistose metagraywacke indicating a normal component of displacement (down to the east). **Inset C:** Conjugate fault surfaces oriented 100/75 and 70/75 with slickenlines oriented 290/12 and 250/20 respectively, bounded by fault planes in clayey fault gouge. Slickenlines indicate oblique-normal components of movement. **Inset D:** Fault-parallel

fractures in weathered bedrock in the fault footwall; rotated and aligned rock clasts within the colluvial deposit in the fault hanging wall.

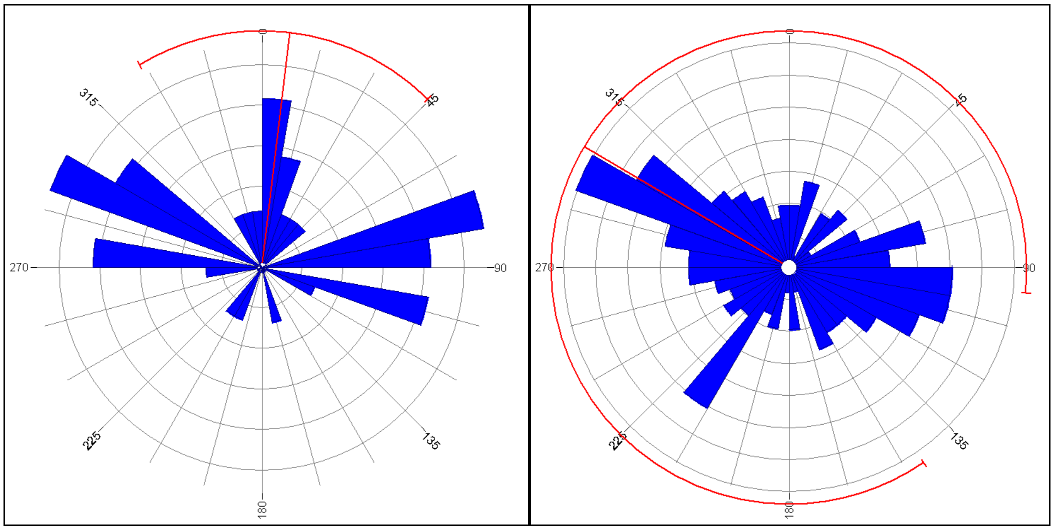

Figure 4-8 Rose diagrams of brittle structural features in the Mills Gap area. **Left:** Fault and breccia orientations, N=36. **Right:** Fracture (joint) orientations. N=256. Both diagrams illustrate the dominant WNW- and ESE-striking brittle fabrics associated with the Mills Gap fault zone; and the subordinate population of NE- and SW-striking brittle structures in the study area.

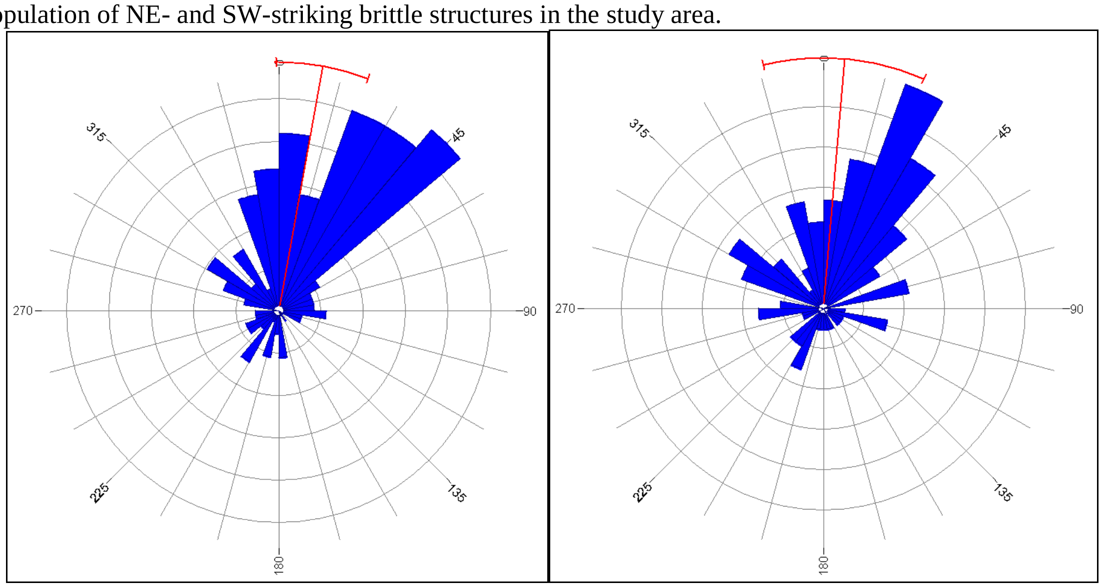

Figure 4-9. Rose diagrams of ductile structural features in the Mills Gap area. **Left:** foliation orientations N=179. **Right:** mylonitic foliation orientations, N = 93. Both diagrams show the dominant NE-striking orientations for the foliation and mylonitic foliation; and, the subordinate population of WNW-striking ductile fabric associated with the Mills Gap fault zone.

References

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Stop. 5 Lorraine Drive Landslide

Leader. Stephen Fuemmeler, Appalachian Landslide Consultants, PLLC.

Location. U.S. Highway 19, Maggie Valley and Lorraine Drive. Longitude -83.013721W, Latitude 35.52628N.

Background. This stop is an example of multiple factors contributing to slope instability. Here we will visit a weathered rock slide that is moving at differential rates in different portions of the slope. The most active area is just upslope of Highway 19 (Figure 5-1). Other portions of the slope that are showing active movement are to the east of Lorraine Drive. Portions of the slope to the west and southwest of the central power pole show evidence of past activity, but not within the past year.

History of Movement. From our observations, it appears that this landslide could be the reactivation of a larger, much older landslide in this cove (Figure 5-2). The widening of Hwy 19 to four lanes in 1969-1970 could have triggered this reactivation. NCDOT personnel recall movement in this area dating back at least to the 1990s, and possibly earlier.

From late summer 2012 through summer 2013, the NCDOT observed an increase in movement rate, which coincided with above average rainfall (Figure 5-3). The slope was laid back and 12 horizontal drains were installed Aug-Sept 2013 (Figure 5-4), which slowed the movement until December 2013. Since December 2013, the NCDOT maintenance division has needed to remove soil from behind the concrete barriers periodically. You will notice that all but two of the horizontal drains have been covered by recent movement.

Factors that Contribute to Movement. The bedrock in this slope is migmatitc schistose metagrawacke and micaceous schist that ranges from completely decomposed to stained state. Multiple joint sets are covered in a slick red clay layer. One of these joint sets is dipping in the same direction as the slope, providing a surface for the slide to move upon. The compositional mineral layering in the rock, combined with the joint sets, provides pathways for the abundant groundwater found on this slope.

Human modifications to this slope have also contributed to its movement. Removal of the soil at the toe along the highway reduces the resistance for slope movement. Three homes on the slope are on septic systems and city water, adding water to the slope that would not naturally be there. Landowners report at least three waterline breaks in the past year on this slope. The storm water runoff ditch along Lorraine Drive directs water onto the most active portion of the landslide near the highway.

Impacts of Movement. This landslide has impacted several parties including the DOT, homeowners, Duke Progress Energy, and the Maggie Valley water department. The most obvious of these is the NCDOT. Hwy 19 has been impacted by the continual need for keeping soil off of the road. Water from the springs kept the road constantly wet or icy during the winter months in 2013. Traffic accidents have resulted from these conditions.

At least three homes on this slope have been impacted by this slide. Two have had their foundations reinforced with steel beams. The third has minor cracking. Two porches have had to be reinforced or rebuilt because they are pulling away from the houses. We will visit one of these to see the foundation reinforcement and cracking, as well as the scarps that have prevented the use of the driveway.

Duke Progress Energy contracted Appalachian Landslide Consultants, PLLC (ALC) to determine if their power pole was in danger. This power pole holds the transmission lines through which all of the electricity in Maggie Valley is carried. The guy anchors for this pole are seated on the slide and have had to be relocated. ALC noted that the relocated guy lines are still within the actively moving portion of this landslide. Duke Progress Energy is currently deciding how to proceed to maintain these transmission lines.

The Maggie Valley water department has had to repair water lines multiple times and will likely have to continue repairing these water lines as long as people still live in this area.

Ways to Decrease Movement Rate (Potentially). Removing as much water from the slope as possible is one way to help slow the movement rate of the landslide. This includes rerouting water lines around the active portion of the slope so they don't break, converting landowners to city sewer rather than septic, rerouting storm water runoff, and installing drains at spring heads and in the ponded areas on the slope to divert water away from the slide.

Reducing the soil removal at the toe, to the extents possible, may help reduce the rate at which the slope is failing. More permanent stabilization structures are most likely necessary to shore up the most active area of this landslide. There are currently no plans for permanent repair of any of the above factors.

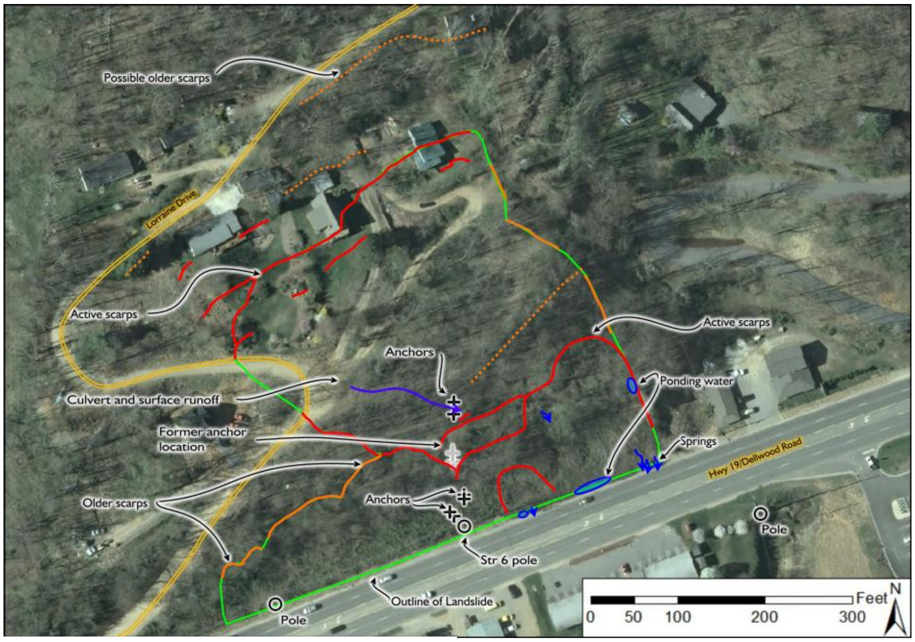

Figure 5-1. Map of Lorraine Drive landslide features.

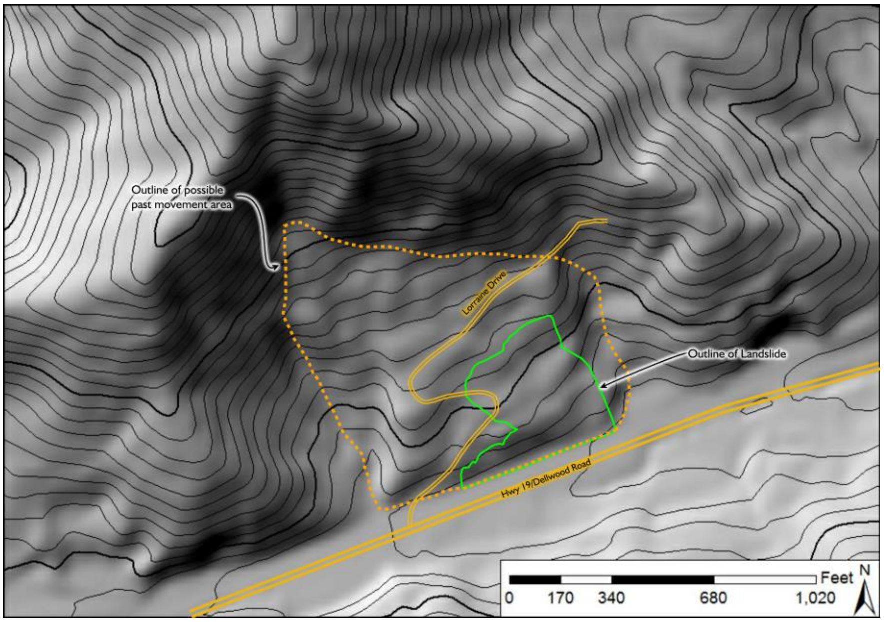

Figure 5-2. Lidar hillshade map showing the extents of a possible older landslide and area showing active movement. Contour interval = 20 feet.

Figure 5-3. Scarps of the most active portion of the Lorraine Drive landslide.

Figure 5-4a. Twelve horizontal drains were installed in September, 2013 by the NCDOT. Photo courtesy of the NCDOT.

Figure 5-4b. Horizontal drains in May, 2014. The landslide has covered 10 of the 12 drains.

Stop 6. 1977 and Older Debris Flow Deposits – Rocky Branch

Leaders: Rick Wooten, Bart Cattanach, Nick Bozdog, N.C. Geological Survey

Location. Rocky Branch off Forest Road 479, Bent Creek Experimental Forest, Pisgah National Forest. Longitude -82.659801W, Latitude 35.46654N.

Background and Purpose. At this stop we will look at the deposits and landforms associated with November 1977 debris flows, and older debris deposits near U.S. Forest Service Road 479. Pomeroy (1991) mapped the debris flow tracks from the November 5-7, 1977 storm in the Bent Creek area of Buncombe County. The November storm was an extratropical cyclone that originated in the Gulf of Mexico (Neary and Swift, 1987), and triggered debris flows in the Bent Creek area of Buncombe and Henderson Counties, and in the Mt. Mitchell-Black Mountains area of Yancey County. Here at Rocky Branch, five debris flow source areas and tracks coalesced into one lower track and run out zone (Figs. 7 and 8). As part of the landslide hazard mapping for Buncombe County, the NCGS and Buncombe County cooperated to scan and geo-register 1982 aerial photography for use as a mapping tool in GIS (Figure 7-left). This approach allowed Pomeroy's mapping to be refined using debris flow tracks visible in the 1982 aerial photography, and topographic contours and shaded relief maps derived from a LiDAR DEM.

Here, like in many cases observed in our mapping in Macon, Watauga and Buncombe Counties, modern debris flows deposit material where there is evidence of past, usually multiple, deposits from previous debris flow events. In their lower reaches, modern debris flows usually follow drainages incised through and along the margins of older debris deposits. In some cases, like we observe here, modern debris flows escape the drainages and deposit material on the older fan surfaces above the stream banks. One possible reason for that occurrence at this location is that the volume of debris from five source areas was more than the single channel in the run out zone could contain. Debris flows can also escape channels when their velocity and volumes are sufficient for them to overtop stream banks on the outside of channel bends.

Shaded relief maps, topographic contours and slope maps derived from LiDAR DEM's are used extensively to identify and delineate debris fan deposits prior to fieldwork. This approach targets areas to verify and helps in making the necessary adjustments to the deposit outlines during the fieldwork phase of landslide hazard mapping. Lobe-and stringer- shaped landforms, coarse-grained debris deposits, and viable upslope source areas are among the criteria we use to standardize the identification and mapping of debris deposits from past mass-wasting events (Bauer et al, 2009).

In addition to indicating areas of past debris flow and other mass-wasting events, mapping these deposits shows the locations of thick accumulations of unconsolidated material that can be destabilized by steep excavations. It is not unusual to encounter wet weather springs and shallow groundwater in debris deposits. These features can influence surface drainage design and foundation design, construction and performance. Because debris fans are typically made up of deposits of various ages, the nature and grain-size of the soil matrix, and weathering state of the rock fragments can vary considerably.

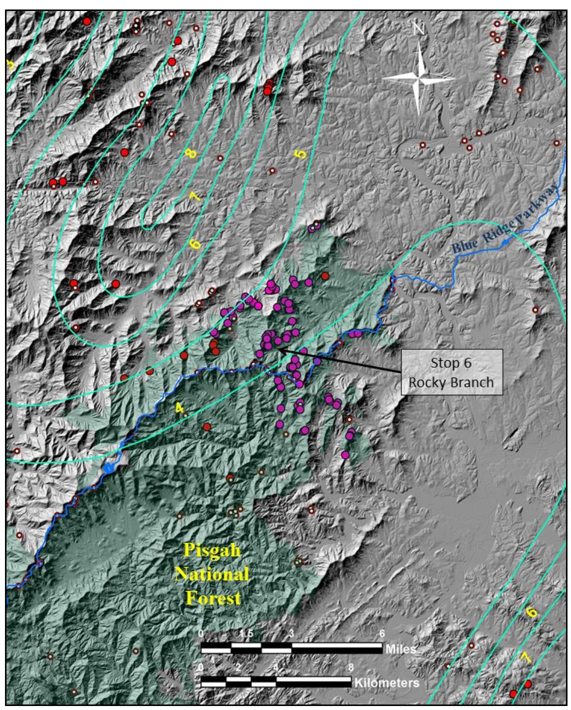

Figure 6-1. Location map showing the location of Stop 6 at Rocky Branch in the USDA-Forest Service Bent Creek Experimental Forest, a unit of the Pisgah National Forest. Purple dots = point locations initiation sites for debris flows triggered by the November 5-7, 1997 storm. Other dots indicate landslide initiation sites from other storms (mainly September 2004). Blue lines are isohyetal contours for the total rainfall in inches for the November 1977 storm event (from Neary and Swift, 1987). Landslide point locations and tracks from Pomeroy (1987), and Wooten and others (2009).

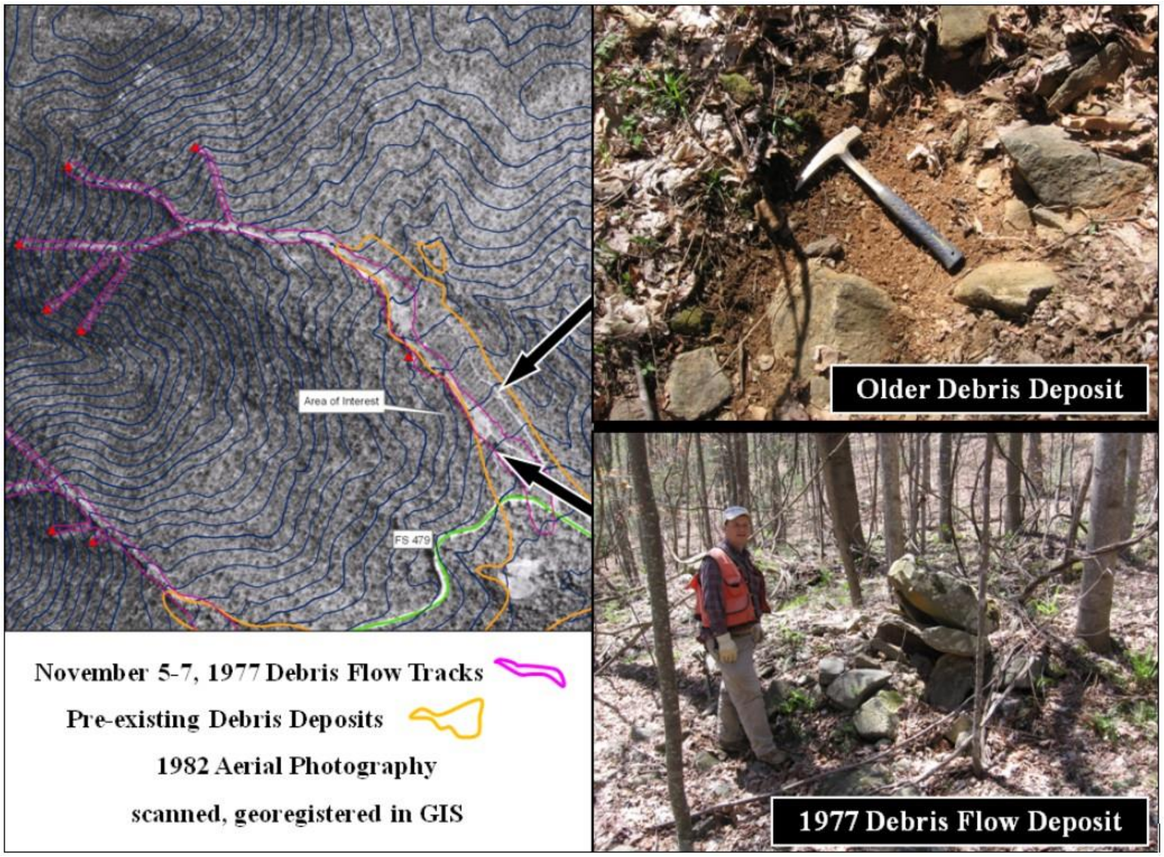

Figure 6-2. Left. Debris flow and deposit features shown on a geo-registered 1982 aerial photograph with LiDAR-derived topographic contours. **Bottom Right.** Imbricated boulders from the 1977 debris flow deposited on top of the pre-existing fan surface. Geologist for scale. **Top Right**. Pre-existing debris deposits exposed on the gentle slope of the older debris fan surface. Note the brown soil matrix around subangular gravel, cobbles and boulders.

Exposed surface debris flow deposits from the 1977 event are primarily remnant gravel-sized and larger rock fragments (Fig. 6-2, bottom right). Most of the sand-sized and finer-grained fractions of the original deposits have since been washed away. Boulder trains, imbricated boulders, and disrupted drainage patterns characterize exposures of the 1977 deposits. Older debris deposits are exposed in roadbeds and cut slopes and in some stream banks. They typically consist of subangular to subrounded gravel, cobble and boulders in a brown, to yellow-brown silty sand matrix (Fig. 6-2, upper right).

Figure 6-3 shows the site area on excerpts adapted from the landslide hazard maps of Buncombe County (Wooten and others, 2009). These three maps show where landslides and landslide deposits are located (Fig. 6-3A); where shallow translational landslides like debris flows and debris slides are likely to start (Fig. 6-3B); and, if debris flows occur, where they will likely travel (Fig. 6-3C).

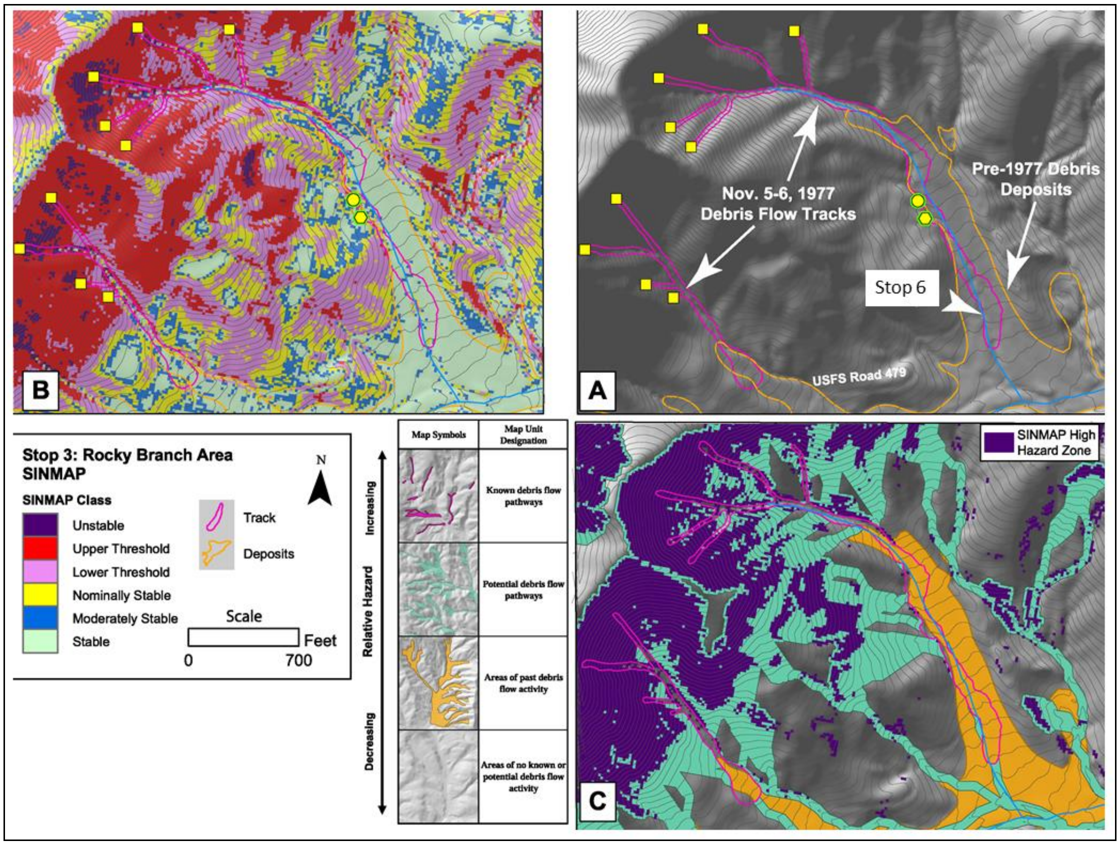

Figure 6-3. A. Debris flows and deposit features shown on a shaded relief map with topographic contours derived from a LiDAR DEM. **B.** Stability index map of the area showing debris flow and deposit features. This color-coded map delineates the predicted stability zones for the initiation of shallow, translational slope movements (e.g., debris flows and debris slides) on unmodified slopes in response to 5 inches or more of rainfall within a 24-hour period (see Pack and others, 1998). **C.** Debris flow pathways map of the area showing known and potential debris flow pathways, and areas of past debris flow activity (deposits). The potential debris flow areas are delineated using hydrologic flow paths that originate from the high hazard zone (unstable and upper threshold) areas of the stability index map, with a 10m (33ft) buffer on either side of stream channels.

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Acknowledgments

The field trip leaders would like to thank Sue Buchanan and Alex Rutledge with Schnabel Engineering South, P.C., for making the field trip announcements, and arranging the details for transportation and food on behalf of the AEG - Carolinas Section. Thanks also go to Schnabel Engineering for covering the cost of printing the guidebooks. We thank Lee Hensley, City of Asheville Water Department, for his cooperation and assistance in having weekend access to their water tank facility on Mills Gap Road. Thanks also go to the USDA-Forest Service staff members at the Bent Creek Experimental Forest who have facilitated landslide studies and access to Rocky Branch for several field trips. Rick Lockamy, NCDOT, provide the 3D oblique LiDAR imagery in Figure 1-2. Brett Laverty, DENR-DWR provided the water well data in Table 1.1.

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